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General and Task-Related Experiences Affect Early Object Interaction

Michele A. Lobo, James C. Galloway, and Geert J. P. Savelsbergh

The effects of 2 weeks of no, general, and task-related enhanced movement experiences on 8- to 12-week-old infants' ($N = 30$) hand and foot interactions with objects were assessed using standard video and motion analysis. For hand–object interaction ability, general and task experience led to greater success than did no experience, and task experience led to greater success than did general experience. Only general experience led to greater success for foot–object interaction ability. Experiences therefore resulted in differential effects depending on which limbs infants used. The results suggest that different movement experiences can advance infants' earliest object interactions. They also indicate that even early purposeful behaviors result from a complex interplay of experience, current ability, and task demands.

The role of experience in the emergence and development of early motor behaviors during infancy is a fundamental issue for developmental psychology (Adolph & Eppler, 2002; Thelen et al., 1993) as well as the foundation for modern early intervention programs (Ulrich, Ulrich, Angulo-Kinzler, & Yun, 2001; Willis, Morello, Davie, Rice, & Bennett, 2002). A large body of evidence exists on the role of experience in altering performance of early motor behaviors that are already present at the initiation of the studies, including kicking (Rovee & Rovee, 1969; Thelen, 1994), early stepping (Vereijken & Thelen, 1997; Zelazo, Zelazo, & Kolb, 1972), sitting (Zelazo, Zelazo, Cohen, & Zelazo, 1993), crawling (Adolph, Vereijken, & Denny, 1998), postural responses (Sveistrup & Woollacott, 1997), and object handling (Needham, Barrett, & Peterman, 2002). What is less clear is whether experience influences the initial emergence of early motor behaviors.

Although there is consensus that experience influences early development, these influences are

complex and often nonintuitive (Gottlieb, 1992). For example, experience actively locomoting using a baby walker has not been shown to advance the onset of crawling or walking and has even been shown to delay the onset of typical independent walking patterns (Kauffman & Ridenour, 1977; Siegel & Burton, 1999). On the other hand, similar self-produced mobility has been found to facilitate infants' abilities to use optical-flow information for improved postural control and performance in a visual cliff paradigm (Anderson et al., 2001; Campos et al., 2000). Further examples of the nonintuitive effects of experience on future behaviors include early discrimination training resulting in poorer performance on discrimination tasks in rhesus monkeys (Harlow, 1959), early visual stimulation resulting in poorer auditory discrimination abilities in quail chicks (Lickliter, 1990), and supine sleeping position resulting in later development of a wide range of motor milestones across the 1st year of life in human infants (Davis, Moon, Sachs, & Ottolini, 1998). Thus, although experience clearly matters, empirical data are necessary to validate even the most seemingly intuitive connections. The present study addresses the need for a systematic assessment of the role of different types of movement experiences in the emergence of object interaction behaviors.

Understanding the emergence of object interaction is particularly important because this ability significantly expands opportunities for further development (Gibson, 1988; Thelen & Smith, 1998; von Hofsten, 1997). For example, the ability to contact objects has effects on visual and oral exploration of objects (Needham et al., 2002), knowledge of object boundaries (Needham, 2000; Dueker, Modib, &

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Needham, 2004), postural stability (Hadders-Algra, Brogren, & Forssberg, 1996), and arm use during crawling (Goldfield, 1989). Furthermore, because young infants cannot yet locomote to objects for exploration, the development of object interaction relies heavily on early caregiver–infant object play relations. In turn, infants' abilities to interact with objects trigger social changes in the caregiver–infant dyad that give rise to increased opportunities for object exploration and turn taking that promote further motor as well as language development (Fogel, 1997; Newland, Roggman, & Boyce, 2001; von Hofsten, 1997).

The first purpose of this study was to determine whether infants who were not yet reaching with their hands would display advanced abilities to contact objects after being provided with enhanced movement experiences. Because of the complex relationships between experience and development mentioned earlier, the theoretical connection between movement experience and the ability to contact objects remains a basic question in need of empirical testing. We assessed motor competency at multiple levels: number of infants contacting the object, contact frequency and duration, and spatiotemporal aspects of limb movements relative to the object. Based on previous findings about the effects of experience on skills already present, we hypothesized that young infants who received enhanced experiences would learn to interact more successfully with objects than would infants who did not receive such enhanced experiences.

The second purpose of this study was to determine the effects of two fundamentally different types of experience—general movement experience and task-related movement experience—on infants' abilities to interact with objects. Infants in the general-experience group had their limbs tethered to an overhead toy to encourage a range of limb movements as in the mobile reinforcement paradigm used to study early memory (Rovee & Rovee, 1969). Early limb movements, such as arm flapping and leg kicking, have long been proposed to provide young infants with opportunities to explore their capabilities and to learn how to move in the external world (Adolph, Eppler, Marin, Weise, & Wechsler-Clearfield, 2001; Robertson, Bacher, & Huntington, 2001; Rochat, 1997; Turvey & Fitzpatrick, 1993; von Hofsten, 1997). Here, we tested for the first time whether there is a connection between such general movements and the emergence of purposeful object interaction. Because we believe early general limb movements provide information necessary for later

prospective control, we hypothesized that infants with general experience would more successfully interact with objects than would infants without enhanced experiences.

Infants in the task-related experience group were provided specific opportunities and assistance for contacting midline objects. This experience, by design, differed from general experience in that it encouraged the performance of a more limited range of limb movements that were specific to reaching for and contacting objects. Practice of a movement or skill that is already present can increase and advance the performance of that movement even in very young infants (Needham et al., 2002; Sveistrup & Woollacott, 1997; Vereijken & Thelen, 1997; Zelazo et al., 1993; Zelazo et al., 1972). Consequently, we hypothesized that improvements in the emerging skill of contacting objects would be noted for infants with task experience relative to infants without enhanced experiences. Altogether, we hypothesized that the performance of the two distinct types of movement experiences would lead to advanced emergence of object interaction. Because this was the first study comparing the effects of different experiences on the development of early object interaction, it was unclear whether there would be differential effects of the two experiences.

The third purpose of this study was to assess the effects of movement experiences on infants' use of both their arms and their legs to interact with objects. Recent work suggests that young infants have greater purposeful control of their legs than their arms during the first months of life. For example, by 12 weeks of age, infants can produce specific leg movement patterns and postures required to move a mobile (Angulo-Kinzler, Ulrich, & Thelen, 2002; Chen, Fetters, Holt, & Saltzman, 2002; Thelen, 1994). Moreover, when provided with opportunities to contact objects, young infants contact with their feet several weeks before they do with their hands (Galloway & Thelen, 2004). Consequently, we expected that, although infants were to begin the study when they were not yet contacting objects with their hands, most of the infants participating in this study would be able to contact objects with their feet on the first visit. This provided the interesting opportunity to examine the effect of experience on infants' abilities to use different limbs for the same purpose of object interaction. We hypothesized that foot–toy interaction, like hand–toy interaction, would be advanced with enhanced experiences. However, it was unclear whether there would be differential effects of the two experiences on the use of the arms and legs to interact with objects.

Method

Participants

Before Visit 1, 30 infants were assigned randomly (irrespective of participant sex) to one of three groups: the no-enhanced-movement-experience control group (4 girls, 6 boys; age at Visit 1: $M = 70$ days, $SD = 10$ days, range = 56 to 85 days, the general-enhanced-movement-experience group (5 girls, 5 boys; age at Visit 1: $M = 74$ days, $SD = 10$ days, range = 58–87 days), or the task-related-enhanced-movement-experience group (1 girl, 9 boys; age at Visit 1: $M = 76$ days, $SD = 10$ days, range = 55–88 days). We located families with infants through local birth announcements, and the families responded to mailed invitations. Infants were healthy Caucasians from two-parent families. Eight additional infants whose parents had indicated interest in participating were excluded from the sample. One was excluded because of scheduling conflicts. Three were excluded because of parents' inability to provide the required home experience. We requested that parents provide the experiences daily yet emphasized that missing occasional days would be an acceptable reality. Provision of home experience was sufficient if it occurred on more than 60% of the days between visits (parents were unaware of this criterion). See the Results section for specifics on parental reports of provision of experiences. Parents reported in journals how much experience was provided daily. We did not make other attempts to ensure compliance. The other 4 infants (1 no experience, 2 general experience, 1 task experience) were excluded because of advanced hand–toy interaction skill at Visit 1 evidenced by more than five hand–toy contacts. Excluding these infants was important because the focus of this study was to assess the effects of the experiences on the initial emergence, not advancement, of hand–object interaction. Parents of all infants provided informed consent.

Procedure

Families visited the laboratory at the Vrije Universiteit for two visits separated by 11 to 17 days (no experience: $Mdn = 14.5$ days, range = 12 to 17; general experience: $Mdn = 14$ days, range = 12 to 16; task experience: $Mdn = 14$ days, range = 10 to 16). At each visit, infants were placed in a specially designed seat and secured with straps and supports for the head and trunk to allow safe play when the chair was placed horizontal or vertical (see Figure 1). The seat allowed free movement of the head, arms, and legs.

In each of the two seat positions, horizontal and vertical, infants were offered fifteen to twenty 12-s



Figure 1. One volunteer positioned vertically in the seat within the laboratory. Infants had their trunks secured but had freedom of movement of their arms and legs. The seat also rotated to position infants horizontally.

opportunities to interact with a stationary toy held by an examiner. Our goal was to collect 15 trials in each condition. At times we collected more to compensate for trials when infants were not in a good behavioral state or when motion analysis markers fell off of the limbs. Placing the infants in two positions helped maximize the total time infants would participate. For instance, at times infants appeared more content and alert horizontal because of tiredness, whereas at other times infants appeared more content and alert in vertical because of intestinal gas. All infants began sessions with the seat horizontal because pilot infants appeared frustrated and were less cooperative when placed horizontal after being vertical. The toy was held at approximately 75% of an infant's arm's length at chest height or 75% of an infant's leg length at hip height in midline. Trials began when infants were visually attending to the toy. A high-speed motion analysis system (Optotrak) was used to track 10 markers at 100 Hz: 2 on the toy, 1 on the center of the dorsal side of each hand and foot, and 1 on the lateral aspect of each wrist and ankle. Two synchronized video recordings provided right and left frontal views of the infants for coding.

Following the toy trials, infants were videotaped during floor play with parents to determine ratings on the Alberta Infant Motor Scale (AIMS), a scale of general motor development (Fetters & Tronick, 2000;

Piper, Pinnell, Darrah, Maguire, & Byrne, 1992). In addition, body mass (g) and length (cm) were recorded and used to determine the Ponderal index (Shirley, 1976; Thelen, Fisher, & Ridley-Johnson, 1984), a measure of chubbiness, based on the formula: $\text{Mass}/\text{Length}^3 \times 100 \text{ (g/cm}^3\text{)}$.

Enhanced Movement Experiences

Families in the control group were not asked to alter their typical daily activities during the interval between Visits 1 and 2. General- and task-experience families conducted 20 min of daily experience with their infants in supine, 5 min per arm and 5 min per leg, which they tracked in journals. The toys used for the home experiences were different from the one toy used for all testing in the laboratory.

General Experience

Parents engaged their infants in play that resulted in greater limb movements by tethering their infants' wrists or ankles, one at a time, to an overhead toy using a ribbon. Parents tethered their infants' limbs to either their own crib mobile or one of two toys provided for them for the duration of the study (a string of colored beads or a colorful wooden toy filled with jingle bells). The toys were held or mounted so they hung above the infants' chests in view but out of reach. Parents alternated use of the mobile and the toys throughout the 2 weeks between visits. The ribbon tethering each infant's limb to the toy was taut when the infant's arm or leg was held away from the toy and near the support surface. In effect, general movements were reinforced and the overhead toy moved in a manner contingent with the amount and vigor of motion of the infant's limb (Rovee & Rovee, 1969). This procedure was repeated daily for 5 min for each arm and leg. This type of experience was termed general because it encouraged a wide range of movements that were not specific to the task of contacting midline objects.

Task-Related Experience

Parents were instructed to teach their children to reach for a midline toy using the hands and feet. Parents performed the following steps: (a) hold the infant's hand or foot in his or her view for several seconds; (b) hold a toy in the infant's view several seconds; (c) passively move the infant's hand or foot to the midline toy and move it on the toy for tactile feedback several seconds; (d) repeat the preceding steps 10 to 15 times, then hold the toy at midline

above the chest or hips 30 s to provide the opportunity for the infant to reach actively for the toy; (e) repeat the preceding steps for 5 min with each hand and each foot. When infants were actively reaching for the toy, parents allowed them to continue until they moved their hands or feet away from the toy. Then parents resumed the steps as described.

Data Analysis

Only trials where infants were awake and moving but not crying were included in the analysis (Behavioral States 3 and 4 from Prechtl, 1974). Table 1 shows the number of trials eliminated because of behavioral state for each group across visits. There were no systematic differences among groups in terms of the number of trials eliminated. Data collected with the seat horizontal and vertical were collapsed for analysis because there were no qualitative differences related to any variable. Right and left limb variables were summed, such that, for example, one bilateral contact was counted as two contacts.

Coded Variables

For each variable coded from video, data from one primary coder were used while two secondary coders blind to the interventional status of the infants coded 42 min of data (6 min from each of 7 infants). Coding reliability was assessed based on the strict comparison of agreements and disagreements. Each time one coder coded an occurrence of behavior, the other coder either coded similarly (agreed) or differently (disagreed). For instance, coders either agreed or disagreed on a given contact's occurrence or on whether an infant was visually attending to the toy at any given second. For each variable, the number of times coders agreed or disagreed was totaled for the duration of analysis and percentage of reliability was calculated using the equation:

Table 1

Numbers of Trials Eliminated From Analyses for the Control, General (GE), and Task-Related (TE) Enhanced Movement Experience Groups Due to Behavioral State

Visit/condition	Control	GE	TE
Visit 1 hands	2	5	1
Visit 2 hands	7	5	5
Visit 1 feet	4	9	5
Visit 2 feet	12	6	12

[Agreed/(Agreed+Disagreed)] * 100. Interrater agreement for each coded variable was greater than 90%.

Number and duration of toy contacts. Toy contact occurred when any surface of the hand or foot contacted the toy. The duration of each contact was coded using the time code superimposed on the video. The beginning and end of each contact were coded based on seconds. The accuracy in coding the duration was approximately 1 s.

Type of toy contact. To provide more information on the type of hand contact, the hand surface (ventral or dorsal) and hand posture (open or closed) at contact were coded. Hand posture was coded at two times: at contact and after contact. An open hand occurred when the fingers extended away from the palm greater than 50% of their range.

Visual attention to the toy. Coding of visual attention was done during trials when infants were in a vertical position so both the eyes and toy could be clearly observed. Although not coding visual attention in the horizontal position could limit the results, we wanted to rely only on visual attention data that could be reliably measured. The percentage of the total coded session time spent looking at the toy at Visit 1 was subtracted from that at Visit 2 for each infant, then averaged to get a group change value.

Motion Analysis Data

To assess hand and foot movement relative to the toy throughout all trials, including trials or portions of trials in which there was no toy contact, motion analysis data were compared among groups. Marker data from a trial were used if the marker was present for more than 70% of the trial without disappearing from view for more than 120 consecutive ms (Corbetta & Thelen, 1999). If the dorsal hand marker met these criteria for a trial, its data were analyzed. Otherwise, we used wrist marker data that met the visibility criteria. The same process was applied to determine whether to use the dorsal foot or ankle marker data. All marker data were passed through a low-pass fourth-order Butterworth filter with a 5 Hz cutoff frequency.

Minimum limb-toy distance. For an infant, the minimum hand-toy or foot-toy distance was calculated for each trial.

Duration spent near the toy. The limb-toy distance for every Optotrak sample (100 samples/second) of each trial was determined. Before each infant's session, the distance between each limb and the toy at toy contact, the contact distance, was determined by touching the toy to the infant's hands and feet in different configurations. Because our primary inter-

est was whether infants spent more time closer to the toy at Visit 2 compared with Visit 1, we determined the percentage of time spent within 100 mm of the toy contact distance during each trial. A distance of 100 mm was chosen to reflect when infants moved their hands and feet in areas more distant from the toy compared with areas closer to the toy (maximum hand-toy distance ~ 250 mm; maximum foot-toy distance ~ 270 mm). Note that this variable excludes times when infants were contacting the toy. Unlike minimum limb-toy distance, which provides data for one sample in each trial, this variable incorporates data from every sample in the trials.

Statistical Analyses

The following six primary variables were analyzed using individual Kruskal-Wallis (KW) one-way analysis of variance (ANOVA): change in hand- and foot-toy contact number, change in minimum hand- and foot-toy distance, and change in percentage of time the hands and feet spent near the toy. This ANOVA with group as the factor and correction for ties was chosen because of the heterogeneity of variance among the three groups, particularly for change in contact number. If the ANOVA resulted in $\alpha \leq .05$, KW post hoc tests by ranks with correction for ties were performed, with $\alpha \leq .05$ representing significance (Siegel & Castellan, 1988). Effect sizes were reported in terms of partial eta squared (η^2). To analyze these change variables, each infant's trial data were used. After selection of trials for Behavioral States 3 and 4, the groups had different total numbers of hand and foot trials; therefore, some were randomly eliminated in groups with greater numbers to allow for equality between number of analyzable trials within infants and across groups (see Table 2; Keppel, 1991). This type of analysis allowed us to assess the data without losing information by collapsing it into individual infant averages. It is important to note that the group means obtained using individual averages before random elimination of trials versus after random elimination of trials were significantly correlated ($R^2 = 0.98$, $p = .000$). After random elimination of trials for equality among groups, 276 trials (55.2 min) of data for each limb set per group remained for analysis for each visit.

Duration per toy contact was also analyzed using KW one-way ANOVA and post hoc test by ranks. This type of analysis allowed us to consider each contact occurrence within groups and rank those contacts across the groups to determine statistically whether any group was able to maintain individual

Table 2
Numbers of Trials Randomly Eliminated From Analyses for Each Group

Group	Visit 1		Visit 2	
	Video data	3-D data ^a	Video data	3-D data
	Hand trials			
Control ^b	5	2	9	5
General experience	19	7	30	24
Task-related experience	27	18	19	16
	Foot trials			
Control	18	18	12	0
General experience	7	6	16	15
Task-related experience	24	22	27	24

^aMore video trials were randomly eliminated than were motion analysis (3-D) trials because some 3-D trials had already been eliminated because markers had not met the inclusion requirements (present for more than 70% of the trial without disappearing from view for more than 120 consecutive ms).

^bOne infant in this group performed only half of the session for Visits 1 and 2 for the hands and feet because he cried when placed vertical. This accounts for the, at times, fewer number of trials eliminated for the control group.

contacts longer than the others. Analyses of change in visual attention, AIMS scores, and Ponderal indexes compared single measures for infants across groups using ANOVA.

Results

No differences were found among groups on the AIMS or for the Ponderal index, which indicates groups did not differ in general motor development level or chubbiness. In addition, no differences were observed in the change in visual attention among groups from Visits 1 to 2 during hand play or foot play, implying that attention to the toy did not account for the changes in performance and that training did not affect visual attention in this paradigm. In addition, the amount of enhanced experience was similar, with infants in both experience groups receiving similar number of days of enhanced experience for the hands and feet (general experience: $M = 10.8$, $SD = 1.8$; task experience: $M = 11.7$, $SD = 1.6$) and similar total minutes of experience for the hands (general experience: $M = 110.6$, $SD = 26.1$; task experience: $M = 114.2$, $SD = 22.9$) and for the feet (general experience: $M = 115.6$, $SD = 37.63$; task experience: $M = 87.7$, $SD = 10.1$). As mentioned previously, provision of experience was sufficient for inclusion in the study if it occurred on more than 60% of the days between visits. This percentage was not significantly different between the general- and task-experience groups

(general experience: $M = 77.8$, $SD = 3.7\%$; task experience: $M = 82.4$, $SD = 2.0\%$).

A marker placed at a fixed point on the lower right side of the seat was used as a reference point to determine whether the end of the toy was held in similar positions for infants across groups during testing. Table 3 shows the average toy position and standard error of the mean for infants in each group at Visits 1 and 2 when the toy was placed at the hands and feet. These data, which are in millimeters, demonstrate that the toy was not held systematically closer to infants in any of the three groups and that the toy's position remained relatively constant within each group. ANOVA revealed no significant differences among groups for toy position at Visits 1 or 2 for the hands or feet.

Random assignment resulted in unintended age and sex differences among groups. Thus, we tested whether either factor influenced the change between Visits 1 and 2 in the number of hand- or foot-toy contacts, our two main variables of interest. First, we plotted each of these change variables versus age and found that neither the change in hand-toy contact ($R^2 = .01$) nor the change in foot-toy contact ($R^2 = .04$) was related to age. For influence of sex, we compared the 10 females with the 20 males in the study using KW one-way ANOVA on change in hand- and foot-toy contact numbers. This type of analysis was used because of the uneven participant numbers in the sex groups. Results demonstrated that females and males did not have significantly different changes in hand- or foot-toy contact numbers. This is in agreement with the previous literature that suggests that females and males do not differ in hand-reaching development (Touwen, 1976). Other studies on hand-reaching development have suggested that females are more advanced (von Hofsten, 1984; von Hofsten & Lindhagen, 1979). If this were the case in this study, the control group, composed of the most females, would have outperformed the enhanced experience groups. As discussed later, this was not the case.

Number and Duration of Toy Contacts

Hands

Skilled object interaction requires the ability to contact repeatedly an object for sustained periods. No infants in any group appeared skilled at hand-toy interaction at the first visit. Only 6 of the 30 infants made any hand-toy contacts (1 control infant, 4 general-experience infants, 1 task-experience infant), and no infant contacted the toy more than three

Table 3

Toy Position Relative to the Seat Across Conditions and Visits for the Control, General (GE), and Task-Related (TE) Enhanced Movement Experience Groups ($M \pm SEM$ mm)

Visit/condition	Control	GE	TE
Visit 1 hands	384.2 \pm 4.0	376.7 \pm 5.4	372.7 \pm 5.2
Visit 2 hands	393.1 \pm 4.1	382.1 \pm 4.2	384.7 \pm 5.0
Visit 1 feet	306.3 \pm 3.9	307.0 \pm 2.4	317.1 \pm 2.4
Visit 2 feet	305.5 \pm 2.8	305.8 \pm 2.8	314.3 \pm 2.7

times or for more than 1 s with the hands. By the second visit, infants in the experience groups increased the number of contacts and duration per contact (see Figure 2). Whereas 3 of the 10 control infants contacted the toy only 8 times total with their hands (increase of 7 contacts from Visit 1), 4 of the 10 general-experience infants and 7 of the 10 task-experience infants did so 64 times (increase of 59 contacts from Visit 1) and 143 times (increase of 142 contacts from Visit 1), respectively. ANOVA revealed a significant difference in change in hand-toy contact number between the groups, $H(2) = 57.66$, $p < .001$, $\eta^2 = .07$. Post hoc tests showed that the task-experience group had a greater increase in hand-toy contacts than did both the control group ($p < .001$) and the general-experience group ($p < .001$). There was also a greater increase in hand-toy contacts in the general-experience group than in the control group ($p < .001$).

In addition, ANOVA revealed a significant difference in duration per hand-toy contact among groups at Visit 2, $H(2) = 49.97$, $p = .01$. Post hoc tests

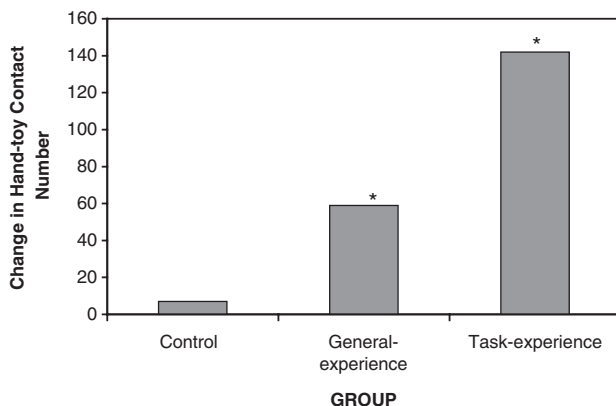


Figure 2. Change in number of hand-toy contacts from Visit 1 to Visit 2 for each group. After 2 weeks of enhanced daily home experiences, the general-experience group had a greater increase in hand-toy contacts than did the control group. The task-experience group had a greater increase in hand-toy contacts than did both the control and general-experience groups. * $p < .05$.

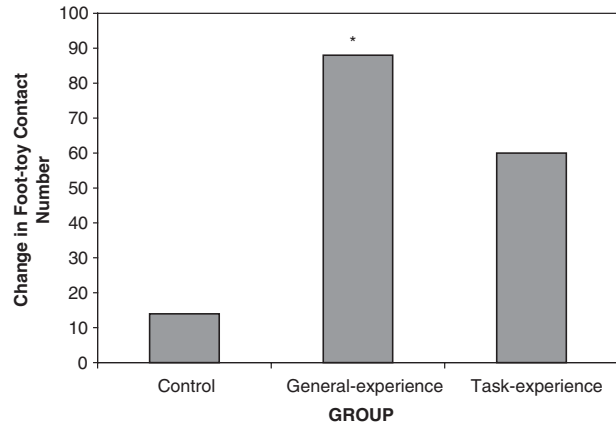


Figure 3. Change in number of foot-toy contacts from Visit 1 to Visit 2 for each group. After 2 weeks of enhanced daily home experiences, the general-experience group had a greater increase in foot-toy contacts than did both the control and task-experience groups. * $p < .05$.

demonstrated that the task-experience group tended to contact the toy for longer periods than did the control group ($M = 2.9$, $SD = .7$ s/contact and $M = 1.3$, $SD = .3$ s/contact, respectively; $p = .09$). There were no differences in duration per contact between these groups and the general-experience group ($M = 2.0$, $SD = .4$ s/contact).

Feet

Although infants were not able to contact the toy with their hands at Visit 1, the majority of infants demonstrated foot-toy contacts. At this first visit, 7 of the 10 control infants contacted the toy 45 times, 8 of the 10 general-experience infants contacted 75 times, and 8 of the 10 task-experience infants contacted 64 times with their feet. By the second visit, fewer control infants (4 of the 10) contacted the toy only 59 times with their feet, whereas all 10 general- and task-experience infants did so 163 times and 124 times, respectively. There was a significant difference in change in foot-toy contact number from Visit 1 to Visit 2 among the groups, $H(2) = 9.50$, $p = .01$, $\eta^2 = .09$ (see Figure 3). The general-experience group had significantly greater increases in foot-toy contacts than did the control group ($p = .01$) and task-experience group ($p = .01$). The control and task-experience groups did not significantly differ, yet the task-experience group had a qualitatively greater increase in foot-toy contacts than did the control group.

There was no difference in duration per foot-toy contact among groups at Visit 1 or Visit 2. For Visits 1 and 2, the average durations per foot-toy contact for

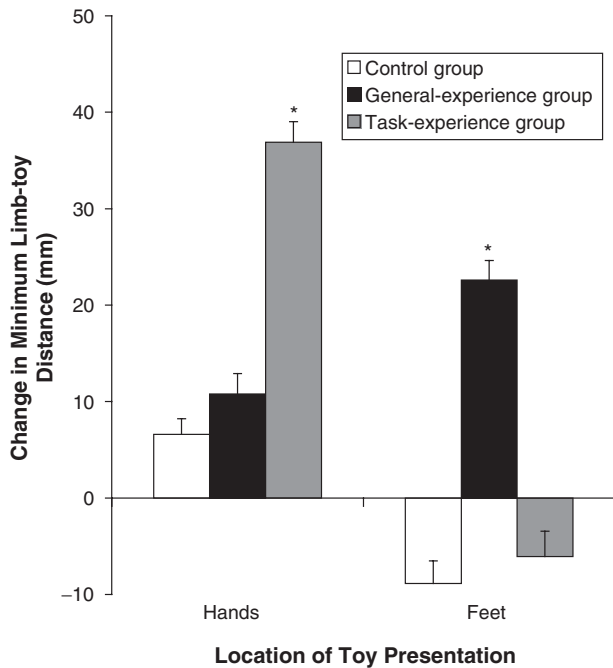


Figure 4. Mean change in minimum limb-toy distance from Visit 1 to Visit 2 for each group (mm). Positive values represent moving closer to the toy at the second visit. Vertical bars represent standard error. After 2 weeks of enhanced daily home experiences, the task-experience group had a greater decrease in minimum hand-toy distance than did both the control and general-experience groups. The general-experience group had a greater decrease in minimum foot-toy distance than did the control and task-experience groups. * $p < .05$.

the control group were $1.2 \pm .4$ s and $1.2 \pm .3$ s, for the general-experience group were $1.1 \pm .1$ s and $1.4 \pm .4$ s, and for the task-experience group were $1.0 \pm .1$ s and $1.2 \pm .2$ s.

Minimum Limb-Toy Distance

Hands

Infants first begin to contact objects consistently with their hands at around 3 to 5 months of age (Thelen et al., 1993; von Hofsten, 1991). Not surprising, some 2- to 3-month-old infants in the present study did not make any hand-toy contacts at Visit 2, and those making contact did not do so on every trial. The average minimum limb-toy distance per trial provided a measure of whether infants moved closer to the toy at Visit 2 versus Visit 1 even if they did not contact the toy. ANOVA revealed a significant difference among the groups for change in minimum hand-toy distance from the Visits 1 to 2, $H(2) = 39.44$, $p < .001$, $\eta^2 = .05$ (see Figure 4). Post hoc tests showed the task-experience group moved their

hands reliably closer to the toy at Visit 2 ($M = 37$, $SEM = 2$ mm) than did infants in the control ($M = 7$, $SEM = 2$ mm; $p < .001$) and general-experience ($M = 11$, $SEM = 2$ mm; $p < .001$) groups. The control and general-experience groups did not differ.

Infants began trials with their hands in an area away from the toy at Visit 1 (control: $M = 186$, $SD = 9$ mm; general experience: $M = 177$, $SD = 12$ mm; task experience: $M = 213$, $SD = 8$ mm from the toy) and Visit 2 (control: $M = 171$, $SD = 10$ mm; general experience: $M = 173$, $SD = 13$ mm; task experience: $M = 162$, $SD = 9$ mm from the toy), suggesting that movement toward the toy during trials was related to the toy's presentation. ANOVA revealed that task-experience infants began trials with their hands farther away from the toy than general-experience infants at Visit 1 ($p = .04$), but no differences were found between these groups and the control group for Visit 1 and no group differences were found for Visit 2. Thus, hand-toy distance results were not confounded by presenting the toy at the beginning of each trial to an already extended arm.

Feet

As for the hands, this variable was informative because there were many trials during which infants did not contact the toy with their feet and some infants never contacted the toy with their feet. ANOVA revealed a significant difference among the groups for change in minimum foot-toy distance from Visits 1 to 2, $H(2) = 18.18$, $p < .001$, $\eta^2 = .05$ (see Figure 4). Post hoc tests showed that infants in the general-experience group moved their feet reliably closer to the toy at Visit 2 ($M = 23$, $SEM = 2$ mm) than did infants in the control ($M = 9$, $SEM = 2$ mm farther from the toy; $p < .001$) and task-experience ($M = 6$, $SEM = 3$ mm farther from the toy; $p = .001$) groups. The control and task-experience groups did not differ.

As for the hands, infants began trials with their feet in an area away from the toy at Visit 1 (control: $M = 183$, $SD = 9$ mm from the toy; general experience: $M = 194$, $SD = 11$ mm from the toy; task experience: $M = 185$, $SD = 8$ mm from the toy) and Visit 2 (control: $M = 188$, $SD = 10$ mm from the toy; general experience: $M = 177$, $SD = 10$ mm from the toy; task experience: $M = 185$, $SD = 8$ mm from the toy), suggesting that movement toward the toy during trials was related to the toy's presentation and the toy was not presented to an already extended leg at the beginning of each trial. ANOVA revealed no group differences for starting distance at Visits 1 or 2.

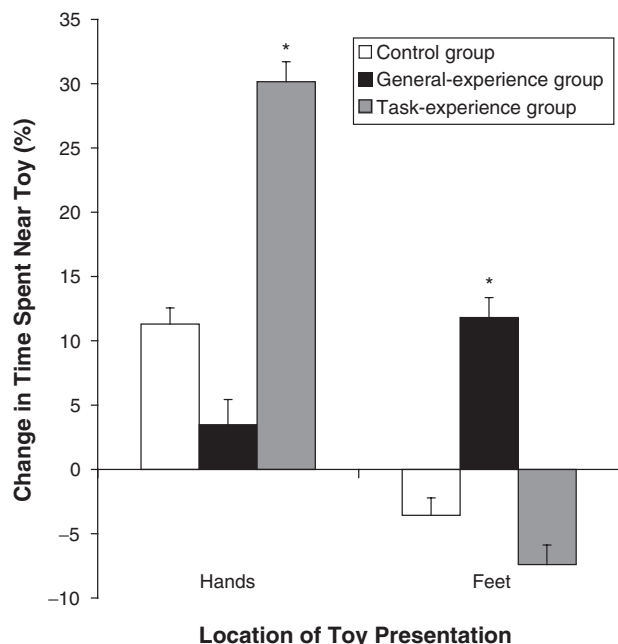


Figure 5. Mean change in percentage of time spent near the toy from Visit 1 to Visit 2 for each group. Positive values represent greater time spent near the toy at the second visit. Vertical bars represent standard error. After 2 weeks of enhanced daily home experiences, the task-experience group held the hands longer near the toy than did both the control and general-experience groups. The general-experience group held the feet longer near the toy than did both the control and task-experience groups. * $p < .05$.

Although the change in minimum limb-toy distance variable includes even trials where toy contact occurred, change in minimum limb-toy distances and change in contact number for infants were not necessarily reliably correlated. These variables were significantly correlated for the hands ($R^2 = 0.16$, $p = .03$) but not for the feet ($R^2 = 0.12$). This suggests that greater improvements in infants' abilities to move closer to the toy may not necessarily accompany greater improvements in the ability to contact the toy.

Duration Spent Near the Toy

Hands

For a more general picture of the behaviors of infants in the study, we considered the changes in percentage of time they held their limbs near the toy (within 100 mm of toy contact distance) between Visits 1 and 2. Only 4 of the 10 control infants held their hands longer in this area at Visit 2 compared with 6 of the 10 general-experience and 9 of the 10 task-experience infants. The average amount of

change was different among the groups, $H(2) = 49.03$, $p < .001$, $\eta^2 = .06$, with the task-experience group showing a greater increase in time the hands were near the toy than the control ($p < .001$) and general-experience ($p < .001$) groups (see Figure 5). The control and general-experience groups did not differ. In addition, infants who decreased their minimum hand-toy distance between sessions tended to spend more of the entire trial time with their hands near the toy ($R^2 = 0.49$, $p < .001$).

Feet

Only 3 of the 10 control and 3 of the 10 task-experience infants held their feet longer near the toy at Visit 2 compared with 7 of the 10 general-experience infants. The average amount of change was different among the groups, $H(2) = 35.29$, $p < .001$, $\eta^2 = .05$, with the general-experience group showing a greater increase in time the feet were near the toy than the control ($p < .001$) and task-experience ($p < .001$) groups (see Figure 5). The control and task-experience groups did not differ. As for the hands, infants who decreased their minimum foot-toy distance between sessions tended to spend more of the entire trial time with their feet near the toy ($R^2 = 0.55$, $p < .001$).

Type of Toy Contact

Hand reaching and grasping can be considered separate but related behaviors that are coupled to allow for prehension (Brinkman & Kuypers, 1973; Jeannerod, 1996; Wimmers, Savelsbergh, Beek, & Hopkins, 1998). The type of hand-toy contact was assessed to determine whether reaching experience had any effect on grasping. To manipulate an object, one typically contacts it with the open, ventral aspect of the hand. It is interesting that neither type of experience appeared to affect hand characteristics related to grasp. At Visit 1, 8 of the 9 (89%) hand-toy contacts totaled across groups (1 control, 6 general experience, 2 task experience contacts) were ventral and with a closed hand on contact. No infant opened the hand after contact. It is surprising that at Visit 2, the percentage of ventral hand-toy contacts decreased for all groups (control = 25%, general experience = 53%, task experience = 52%), whereas the percentage of contacts initiated with an open hand increased to around 50% for each group, a finding consistent with the previous literature (von Hofsten, 1984). All of the groups similarly increased the percentage of contacts in which the hand opened after contact (control = 13%, general experience = 20%,

task experience = 18%). Therefore, reaching experience did not appear to affect differentially variables related to grasp.

Discussion

Experience can influence the development of a behavior by advancing the initial emergence of a behavior (induction), by advancing the development of behaviors already present (facilitation), or by preserving behaviors already present (maintenance; Gottlieb, 1983). Our results provide an interesting example of the facilitative and inductive effects of enhanced movement experiences on early infant behavior. Two types of experiences advanced the emergence of hand interaction and one improved foot interaction with midline objects in infants who began with similar skill levels (see Table 4). Specifically, more general- and task-experience infants were consistently contacting the toy more often with their hands by Visit 2 than were control infants (induction). In addition, more general-experience infants were consistently contacting the toy more often with their feet by Visit 2 than were control and task-experience infants (facilitation).

The general-experience effect supports the theoretical stance that early limb movements not involving direct object contact play an important role in the development of purposeful behaviors. Indeed, certain early movements that appear random and reflexive may be exploratory if not purposeful in terms of active information pickup (Adolph et al., 2001; Robertson et al., 2001; Rochat, 1997; Ruff, Saltarelli, Capozzoli, & Dubiner, 1992; Turvey & Fitzpatrick, 1993; von Hofsten, 1997).

The task-experience effect suggests that experiences that are specific to moving toward and touching objects are also related to the development

of object interaction abilities. Task experience encouraged parents to introduce objects into their face-to-face interactions with infants, to demonstrate object affordances, to assist early reach attempts, and to minimize gradually their assistance as infants demonstrated increasing success. This type of scaffolding to teach affordances and bridging to encourage independent object play typically emerge in caregiver interactions with infants 1 to 2 months older than those in the present study (Fogel, 1997; Fogel, Messinger, Dickson, & Hsu, 1999; Reed & Bril, 1996). Our results provide empirical support for the ideas that: (a) early object play typical in the caregiver–infant dyad advances object interaction abilities, and (b) this type of social play is effective in advancing hand–toy interaction even when introduced 1 to 2 months earlier than is typical.

The effects of both experiences were specific to the development of the ability to contact objects but not to grasping. Infants in this study were still 1 to 2 months from the typical onset of active grasping (Savelsbergh & van der Kamp, 1993; von Hofsten, 1982, 1984). It is unlikely they had significant experience before Visit 1 handling objects, a behavior that might be important to the emergence of active grasping (Needham et al., 2002). In addition, neither experience group received significant object-handling time as part of the enhanced experiences: General experience involved no direct toy contact; task experience involved only brief, passive hand–toy contact. By the end of the study, all infants remained 1 month or more from the typical onset of active grasp during reaching; therefore, it is not known whether either experience advanced the future emergence of grasping.

General and task experiences differentially affected hand– and foot–object interaction skills. Task experience better advanced the emergence of hand

Table 4
Summary of the Results for the Control (C), General (GE), and Task-Related (TE) Enhanced Movement Experience Groups

Variable	Hands	Feet
Number of infants contacting toy ^a	TE > GE > C	GE = TE > C
Change in contact number	TE > GE > C*	GE > C = TE*
Contact duration	TE > C, GE = C, TE	C = GE = TE
Number of infants moving closer to the toy	TE > C > GE	GE > C = TE
Decrease minimum limb–toy distance	TE > C = GE*	GE > C = TE*
Number of infants spending more time near toy	TE > C > GE	GE > C = TE
Increased duration near toy	TE > C = GE*	GE > C = TE*

^aRelationships among numbers of infants are displayed to demonstrate qualitative differences between groups and were not tested statistically.

* $p < .05$.

interaction with objects than did general experience, whereas only general experience led to significant improvements in foot interaction with objects. What did both general and task experiences provide that led to advancement for the hands? And why did general and task experiences lead to different levels of advancement in infants' abilities to use their hands and feet? Although these are empirical questions, we briefly outline issues for consideration.

Similar Effects of the Experiences

Both experiences encouraged exploratory movement that may have provided infants with enhanced opportunities to learn about the biomechanical properties of their limbs and about their capabilities for acting on the environment (Adolph et al., 2001; von Hofsten, 1997). This exploration may have improved prospective control of movements. At home, task-experience infants explored movements that were specific to contacting midline objects and may have developed improved prospective control for this specific action. On the other hand, general-experience infants explored a wider range of movements. This experience may have provided for better prospective control of the limbs for general actions, which infants then used for the specific task of reaching when provided the opportunity to contact toys.

Both experiences may have provided for infants' learning of affordances, albeit through different experiences. Whereas task-experience infants learned affordances that could be directly applied to the toy-contact task at the second visit, general-experience infants learned affordances about distant objects that they then transferred to this task (Adolph, 1997; Gibson, 2000). Task experience provided direct exploration of spatial, textural, and inertial object and self-properties in a social situation with a nearby caregiver and object. Task-experience infants moved their limbs or had them moved toward and on a toy while they looked at and felt the toy, their limb, and an adult holding the toy. General experience provided exploration of a distant object's spatial and possibly inertial properties indirectly through a tether with caregivers either in or out of view. As a result, general-experience and task-experience infants were taught different possibilities for actions with objects. Nonetheless, both experiences advanced hand-object interaction, suggesting that young infants may be able to transfer knowledge about object affordances between certain situations (Gibson, 1997).

Differential Effects of the Experiences

Although both experiences advanced hand-object interaction, task experience advanced hand-object interaction more than did general experience, and only general experience advanced foot-object interaction. In the following, we highlight that object interaction at Visit 2 resulted from the interplay of past experience (2 weeks enhanced experience), limb properties, and the current task requirements (reaching task at Visit 2).

Why did task-experience infants display more advanced hand-object interaction than general-experience infants? Gibson (1997) proposed three steps in the development of purposeful behaviors: (a) perform spontaneous exploratory activity, (b) observe the consequences, and (c) select successful behaviors from the behaviors explored. Task-experience infants performed exploratory activity at home within a narrow task space near or at a midline toy. Repetition of a small set of movements results in repetition of a small set of muscle activity patterns, muscle forces, and joint motions and may have allowed for the formation of cooperative muscle activation synergies and more integrated perceptual-motor maps for better prospective control in contacting midline objects (Bernstein, 1967; Edelman, 1987; von Hofsten, 1997). Task-experience infants may have learned to select movements from their restricted search space to recruit actions that resulted in toy contact (Berthier, Clifton, McCall, & Robin, 1999; Schlesinger, Parisi, & Langer, 2000). At Visit 2, these infants were being assessed for how well they could recall and execute successful behaviors in a familiar context and task space.

General-experience activities encouraged a wider range of exploratory movements. Infants at this age hold their arms lateral or flexed at midline but have difficulty extending their arms into the task space required to contact a midline object (Galloway & Thelen, 2004; Spencer & Thelen, 2000). Thus, it is unlikely that any infant produced frequent arm movements within the task space required for midline reaching before the first visit. Between visits, general-experience infants received reinforcement from an overhead toy using a broad range of movements available in their current repertoire. At Visit 2, these infants were being assessed for how well they could select, recall, and execute successful behaviors from a repertoire of less constrained movements in a novel context within an unfamiliar task space (Bernstein, 1967; Saltzman & Kelso, 1987; Schutte & Spencer, 2002). The general-experience infants in this study were able to do this; however,

they were less advanced with their hands as compared with task-experience infants.

Why did only general-experience infants display more advanced foot-object interaction? Based on the previous assessment of what infants in each group learned in relation to what was assessed at Visit 2, one might expect that task experience would also result in more significant improvements in foot-toy interaction. However, whereas lack of exploration within the required task space and restriction of the limb's area of movement may have limited the general-experience effects for the arms, these were not likely limiting factors for the legs. At 2 to 3 months of age, infants perform a variety of midline leg movements that likely include a subset within the task space required for midline object contact (Jensen, Schneider, Ulrich, Zernicke, & Thelen, 1994; Piek, 1996). Exploration of this subset of movements through general experience may have improved prospective control of the legs and allowed foot interaction with a midline toy. In addition, the legs may well possess a smaller number of neural and biomechanical means for movement than the arms; therefore, constraining these means may not be a significant issue in the development of leg movement control (Bernstein, 1967).

The interplay of the development of infants' use of the hands and feet to interact with objects likely was a significant factor in why general experience resulted in greater improvement in foot-toy interaction as compared with task experience. Previous work has suggested that foot-toy interaction emerges before hand-toy interaction and diminishes once hand-toy interaction emerges (Galloway & Thelen, 2004). Task-experience infants at Visit 2 were more advanced with their hands than were general-experience infants. Task-experience infants may have been less advanced interacting with objects at their feet at Visit 2 because they displayed this more advanced interaction with objects at their hands.

Concluding Remarks

Our results provide important empirical support for the role of movement experiences in the induction and facilitation of purposeful object interaction behaviors in early infancy. They also suggest there can be multiple pathways underlying the development of a single behavior, but certain experiences may be more effective than others in advancing the development of behaviors. The emergence of early purposeful behaviors may be best viewed as the result of a complex interplay of experience, current ability, and task demands. Finally, our results dem-

onstrate the need for further research to assess the effects of such enhanced movement experiences in relation to a control group that receives an equal duration of social interaction and to determine whether such short-term experiences can alter long-term developmental patterns.

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